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REPORT NO. T1-90

EFFECTS OF A MODIFIED THROUGH-MASK DRINKING SYSTEM (MDS) ON FLUID INTAKE DURING EXERCISE IN CHEMICAL PROTECTIVE GEAR

U S ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE
Natick, Massachusetts

NOVEMBER 1989

UNITED STATES ARMY
MEDICAL RESEARCH & DEVELOPMENT COMMAND

TECHNICAL REPORT NO. T1/90

Effects of a Modified Through-Mask Drinking System (MDS) on Fluid Intake During Exercise in Chemical Protective Gear

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PROJECT REFERENCE NOVEMBER 1989 SERIES HR

1 Heat Research Division
2 Health and Performance Division

U.S. ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE
NATICK, MASSACHUSETTS 01760-5007

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE:

3. DISTRIBUTION / AVAILABILITY OF REPORT: Distribution A: Approved for public release; distribution unlimited

4. PERFORMING ORGANIZATION REPORT NUMBER(S):

5. MONITORING ORGANIZATION REPORT NUMBER(S):

6a. NAME OF PERFORMING ORGANIZATION: Heat Research Division, USARIEM

6b. OFFICE SYMBOL *(If applicable)*: SGRD-UE-HR

7a. NAME OF MONITORING ORGANIZATION:

6c. ADDRESS *(City, State, and ZIP Code)*: Kansas Street, Natick, MA 01760-5007

7b. ADDRESS *(City, State, and ZIP Code)*:

8a. NAME OF FUNDING / SPONSORING ORGANIZATION:

8b. OFFICE SYMBOL *(If applicable)*:

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c. ADDRESS *(City, State, and ZIP Code)*:

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
62787A	3E162787A879	Reimbursable Order	For WU129: DA311251

11. TITLE *(Include Security Classification)*: Effects of a Modified Through-Mask Drinking System (MDS) on Fluid Intake During Exercise in Chemical Protective Gear

12. PERSONAL AUTHOR(S): PC Szlyk, IV Sils, WJ Tharion, RP Francesconi, HB Mahnke, Jr., MJ Durkot, CB Matthew, WT Matthew, LE Armstrong, IM Rauch, RW Hubbard

13a. TYPE OF REPORT:

13b. TIME COVERED: FROM Jan 89 TO May 89

14. DATE OF REPORT *(Year, Month, Day)*: 1989 October 12

15. PAGE COUNT: 38

16. SUPPLEMENTARY NOTATION:

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*: MOPP IV, Chemical Protective Gear, Fluid requirements in MOPP, Heat tolerance, Encapsulation, Hypohydration

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

This study was designed to evaluate the effects of a modified through-mask drinking system (MDS) on voluntary fluid consumption. Eighteen male volunteers walked on a treadmill (4.02 km/hr, 0° grade, 50 min/hr for 6 hr) in a climatic chamber (dry bulb=32.6°C, wet bulb=17.5°C, 20.4% relative humidity, and windspeed=8.05 km/hr, producing a WBGT of 22.1°C). Subjects wore chemical protective gear (trousers, jacket, boots, gloves, and M17A1 protective mask) and were randomly assigned one of two through-mask drinking systems: CS (n=9), the current gravity fed system or MDS (n=9), a prototype hand-pump drinking system. Because decontamination of the mask and drinking connections was performed prior to drinking, the overall use of the CS was rated

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION:

22a. NAME OF RESPONSIBLE INDIVIDUAL:

22b. TELEPHONE *(Include Area Code)*:

22c. OFFICE SYMBOL:

19. cont

significantly more difficult during both work and rest than the MDS. Failure to decontaminate connections prior to drinking was noted early in the trial in 2 soldiers using the CS suggesting an increase risk of accidental contamination associated with this system. Drinking with the MDS had no measurable adverse effect on hydration status of the test subjects: water intake rate, 0.36 L/hr (CS) and 0.42 L/hr (MDS); sweat rate, 0.63 L/hr (CS) and 0.67 L/hr (MDS); body weight loss, 0.32 %/hr (CS) and 0.31 %/hr (MDS). The significantly greater frequency of drinking (3 drinks/walk, MDS vs 1 drink/walk, CS) and the trend toward higher intake rates during the walks with the MDS (0.35 L/hr vs 0.24 L/hr, CS) indicates the potential advantage of this system during operations wherein periods of inactivity are usually limited. Heat strain experienced by soldiers drinking with the MDS was significantly less than that with the CS. The significantly greater changes in rectal (1.79°C, CS vs 1.27°C, MDS) and skin (2.47°C, CS vs 1.91°C, MDS) temperatures and heat stored (70 kcal/m^2, CS vs 46 kcal/m^2, MDS) in CS may have been due to the additional work and frustration associated with using this system. Minor effects on performance were observed; exercise times were not different between CS (232 min) and MDS (225 min). The significantly greater dispersion in the vertical shot group measure of marksmanship by MDS may have been related to their reportedly greater level of fatigue. We have concluded from these data that the prototype MDS did not compromise fluid intake during the experimental scenario, and should be more effective and efficient than the CS in maintaining hydration status, especially during periods of work.

ACKNOWLEDGEMENTS

The authors express their sincere appreciation to all of the individuals who contributed to the success of this project. The skilled technical assistance of the following individuals is gratefully acknowledged: Theresa Soucie, Judith Mayotte, Craig Jacobson, Jane De Luca, Elaine Christensen, Brent Marlowe, SSG Glenn Thomas, SSG Osvaldo Martinez, SPC Richard Anderson, SGT Linda Gowenlock, Florence Breslouf, and Leonard Sousa. We thank CPT John Croke, Dr. Everett Harman, Dr. Michael Sutherland, and Donald Davio for their professional consultation. We express our gratitude to Diane Danielski and Jo-Ann DeLuca for typing the report. We especially wish to thank the group of test volunteers for their patience and perseverance in completing these studies.

DISCLAIMER

The views of the authors do not purport to reflect the positions of the Department of the Army or the Department of Defense. Human subjects participated in this study after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USARMDC Regulation 70-25 on Use of Volunteers in Research. Citation of commercial organizations or trade names do not constitute an official Department of the Army endorsement or approval of the products or services of these organizations.

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ABSTRACT

This study was designed to evaluate the effects of a modified through-mask drinking system (MDS) on voluntary fluid consumption. Eighteen male volunteers walked on a treadmill (4.02 km/hr, 0° grade, 50 min/hr for 6 hr) in a climatic chamber (dry bulb=32.6°C, wet bulb=17.5°C, 20.4% relative humidity, and windspeed=8.05 km/hr, producing a WBGT of 22.1°C). Subjects wore chemical protective gear (trousers, jacket, boots, gloves, and M17A1 protective mask) and were randomly assigned one of two through-mask drinking systems: CS (n=9), the current gravity fed system or MDS (n=9), a prototype hand-pump drinking system. Because decontamination of the mask and drinking connections was performed prior to drinking, the overall use of the CS was rated significantly more difficult during both work and rest than the MDS. Failure to decontaminate connections prior to drinking was noted early in the trial in 2 soldiers using the CS suggesting an increase risk of accidental contamination associated with this system. Drinking with the MDS had no measurable adverse effect on hydration status of the test subjects: water intake rate, 0.36 L/hr (CS) and 0.42 L/hr (MDS); sweat rate, 0.63 L/hr (CS) and 0.67 L/hr (MDS); body weight loss, 0.32 %/hr (CS) and 0.31 %/hr (MDS). The significantly greater frequency of drinking (3 drinks/walk, MDS vs 1 drink/walk, CS) and the trend toward higher intake rates during the walks with the MDS (0.35 L/hr vs 0.24 L/hr, CS) indicates the potential advantage of this system during operations wherein periods of inactivity are usually limited. Heat strain experienced by soldiers drinking with the MDS was

significantly less than that with the CS. The significantly greater changes in rectal (1.79°C, CS vs 1.27°C, MDS) and skin (2.47°C, CS vs 1.91°C, MDS) temperatures and heat stored (70 kcal/m^2, CS vs 46 kcal/m^2, MDS) in CS may have been due to the additional work and frustration associated with using this system. Minor effects on performance were observed; exercise times were not different between CS (232 min) and MDS (225 min). The significantly greater dispersion in the vertical shot group measure of marksmanship by MDS may have been related to their reportedly greater level of fatigue. We have concluded from these data that the prototype MDS did not compromise fluid intake during the experimental scenario, and should be more effective and efficient than the CS in maintaining hydration status, especially during periods of work.

BACKGROUND

Adequate supplies of potable water and ample time for consumption of fluids do not always ensure that drinking will be sufficient to restore body water lost in sweat. Rothstein et al. [17] observed that troops marching in the desert heat did not rehydrate adequately and lost as much as 5% body weight even when water was plentiful and palatable. Progressive hypohydration from inadequate fluid intake during work may result in elevated core temperature, increased heart rate, reduced sweating, and increased risk of heat injury. Under the threat of chemical, biological or nuclear contamination, the chemical protective clothing, hooded face mask and the current through-mask drinking system may further reduce voluntary consumption. Even under temperate conditions, work in MOPP IV configuration (chemical protective trousers, jacket, gloves, boots, and hooded M17A1 mask), may cause significant hypohydration and hyperthermia, and may have detrimental effects on psychological, physiological, and performance variables [8,9,10,12,18,21,22].

The current procedures for drinking during masked encapsulation have been described as "...time consuming and difficult to perform. Soldiers in stressful environments have been found to become frustrated and stop drinking the required amount of water..." [23]. This is true because the current through-mask drinking system must be decontaminated, connected and disconnected with every drink [16], a process which requires 21 steps. Also, because this system requires two-handed operation, drinking is cumbersome and difficult particularly when

marching, in dark or cramped conditions, or when injured. Finally, drinking with the current system requires that the soldier first create, then inhale against, a positive pressure which could exacerbate existing respiratory strain.

A modified through-mask drinking system (MDS) prototype was designed to lessen some of the risks and problems associated with the current through-mask system (CS). Two unique features of this MDS prototype are 1) single-handed operation for easy use even under dark or cramped conditions and 2) a one time connection of the drinking tube and canteen which eliminates breaching of the system and lessens the risk of contamination.

MILITARY RELEVANCE AND OBJECTIVE

The military requirement for full encapsulation in chemical protective gear in a contaminated environment poses many problems for the soldier among which is the difficulty in drinking through the protective mask. A modified through-mask drinking system prototype which may eliminate some of the problems associated with the current system, has been developed. It was the objective of this study to evaluate the effects of the new MDS prototype on fluid consumption in soldiers exercising in a moderate environment in chemical protective gear.

METHODS

Test Subjects:

Eighteen (18) unacclimated male volunteers were recruited from the military population at USARIEM and USANRDEC, Natick, MA,

briefed on the nature, purpose and risks of the study and provided written consent to participate. A description of the test subjects is provided in Table 1.

Table 1. Descriptive characteristics of subjects

Variable (Range)	CS (n=9)	MDS (n=9)
Age (yrs) 19 - 42	23.6 ± 3.12	28.0 ± 2.11
Height (cm) 170 - 192.5	178.2 ± 1.7	180.0 ± 2.4
Weight (kg) 55.96 - 90.97	78.82 ± 2.61	76.02 ± 2.98
Surface area (m^2) 1.78 - 2.16	1.95 ± 0.04	1.98 ± 0.04
Body fat (%)[1] 8.2 - 26.6	16.5 ± 2.0	18.6 ± 1.4

Values are Mean ± S.E.
1 Durnin-Womersley [7] formula for percent body fat uses 4 skinfold sites and adjusts for age.
CS Current drinking system
MDS Mask drinking system

Experimental Design:

About one week prior to actual data collection, subjects practiced drinking with the M17A1 mask and their respective drinking system, i.e. the current system (CS) or the modified through-mask drinking system (MDS). Also, subjects trained on the Weaponeer marksmanship simulator until no further improvement in performance was noted.

On the test day, volunteers reported to the climatic chamber facility at 0645 h in a 12 hr fasted state. Breakfast consisted

of instant breakfast (in 450 ml of milk), toast, butter, jam and 450 ml of orange or apple juice. Subjects were encouraged to drink plentiful fluids prior to the test day and during breakfast. Subjects then proceeded to a dressing room for assessment of initial nude body weight, age, height [6], and % body fat [7]. As an index of hydration status, a pretest urine sample was analyzed for specific gravity (refractometry) and no significant difference was observed between the two groups (1.022 $\pm$ 0.002, CS; 1.025 $\pm$ 0.002, MDS). Each subject was fitted with instrumentation for monitoring rectal (Tre, 10 cm depth) and skin (3 point: chest, arm and leg) temperatures as well as ECG to monitor heart rate (HR, 5 min intervals). Shorts, sneakers, socks, and T-shirt were worn under the chemical protective gear (MOPP IV: jacket, trousers, boots, gloves, and hooded mask). Following instrumentation and encapsulation, each subject proceeded to a second room where they were tested for marksmanship on a Weaponeer by firing two sets of nine shots at a zeroing target. Upon termination of the exercise (6 hrs or after medical or voluntary withdrawal, Appendix E), subjects again fired while in MOPP IV configuration. Following the final weaponeer firing, a final nude weight was obtained.

Subjects walked on one of two treadmills set on a flat grade for 50 min of each hr at a rate of 4.02 kph (2.5 mph) in an environmental chamber (db=32.6°C, wb=17.5°C, rh=20.4%, windspeed=8.05 km/hr, WBGT=22.1°C). During the remaining 10 min of each hr, subjects were sedentary. A complete experimental scenario was comprised of six repetitions of this 50/10 min

work/rest cycle for a total endurance time of 6 hr (360 min) and total walk time of 5 hrs (300 min). Subjects were removed when any signs of distress were observed, when preset safety criteria (HR>180 bpm, Tre>39.5°C) were exceeded, or when ordered by the medical monitor. Each subject was randomly assigned to one of two groups based upon the through-mask drinking system: CS, current through-mask water delivery system; MDS, modified through-mask drinking system prototype.

Webb gear and canteens were worn about each subject's waist, and water intake (25°C, 16 mg iodine/l) was measured upon completion of each 50 min walk and 10 min rest, or sooner if necessary, by weighing each 2 qt flexible canteen on an electronic balance (±1 g). At that time, canteens were refilled. Total sweat production was calculated as the difference between final and initial nude body weights, adjusted for fluid intake and measured urine volume and calculated respiratory water losses [15].

Subjects carried a rifle during the walks, and prior to drinking with the current system, soldiers slung the rifle on their shoulders. It was necessary for CS subjects to connect and disconnect canteens from the hooded mask without assistance and perform decontamination procedures before each drink [16]. The frequency of drinking and the number of times decontamination was not performed were recorded. Before entering the test chamber, each subject completed an Environmental Symptoms Questionnaire (ESQ) (weariness, head and bodily aches, hyperthermia, and thirst) after donning the chemical protective clothing but

without the hooded mask. The ESQ was also administered immediately after completing the day's trial while test subjects were still in MOPP IV configuration. During the 2nd, 4th and 6th or final rest periods, each subject rated their drinking system for overall ease of use for both the walk and rest periods. During each rest, subjects rated their feelings of comfort, warmth and tiredness [11], and during each walk, perceived exertion was assessed [4].

"Final" walk values for all variables were obtained for all subjects and represent the last measures prior to termination of a subject's trial. Intrasubject comparisons for the physiological measures were made using the Wilcoxon Matched Pairs test and comparisons between the two drinking systems were evaluated using Friedman ANOVA by Ranks and the Mann-Whitney U test. The Weaponeer data were analyzed by the BMDP statistical software package for repeated measures analysis of variance and descriptive statistics software. Statistical significance was accepted at $p<0.05$ level.

RESULTS

Ratings of the drinking systems (Table 2) suggest that the MDS prototype is a more convenient water delivery system than the CS. Of particular importance are the findings that general ease of use of the MDS was similar during walk and rest periods (extremely easy to easy) and rated significantly easier to use than the CS (neither easy nor hard to hard) during both work and rest. CS subjects rated connecting/ disconnecting the canteen

Table 2. Results from Drinking System Questionnaire

Group	Time	# Subjects	Ease of use during[a] Walk	Ease of use during[a] Rest	Ease of connecting/disconnecting canteen from mask at[a] Walk	Ease of connecting/disconnecting canteen from mask at[a] Rest
CS	Rest 2	7	3.6*	2.9*	3.0	2.7
	Rest 4	8	3.5*	3.1*	3.5	2.9#
	Final	8	3.4*	3.0*	3.6	2.9#
MDS	Rest 2	9	1.9	1.9		
	Rest 4	7	2.0	1.7		
	Final	9	1.6	1.5		

Group	Time	# Subjects	Ease of holding canteen above head during[a] Walk	Ease of holding canteen above head during[a] Rest	Ease of pumping water into mouth during[a] Walk	Ease of pumping water into mouth during[a] Rest
CS	Rest 2	7	3.0	2.4#		
	Rest 4	8	3.5	2.9		
	Final	8	3.6	2.9#		
MDS	Rest 2	9			3.1	1.9
	Rest 4	9			2.4	1.9#
	Final	9			2.4	2.1

Group	Time	# Subjects	Taste Rating[b]	Temperature Rating[c]
CS	Rest 2	7	3.1	2.9
	Rest 4	8	3.1	2.8
	Final	8	3.3	3.0
MDS	Rest 2	9	2.9	3.6
	Rest 4	9	2.9	3.5
	Final	9	2.9	3.3

Values represent average ratings given by group.

a On a scale from 1 to 5; 1= extremely easy, 3= neutral, 5= extremely hard.

b On a scale from 1 to 5; 1= extremely dislike, 3= neutral, 5= extremely like.

c On a scale from 1 to 5; 1= cold, 3= neutral, 5= hot.

* Significant ($p<0.05$) difference between CS and MDS.

\# Significant ($p<0.05$) difference between walk and rest.

from the mask and holding the canteen above the head as "neither easy nor hard" during rest but as "difficult" during the walks. While drinking with the CS was rated slightly easier during rests compared to walks, the MDS group reported that fluid delivery with the hand pump was equally easy during rest and work.

The flow rate (slow to just right) and leakage (none to slight) were similar for CS and MDS. Neither drinking system had any effect on the perception of either water taste (neither like nor dislike) or temperature (neither cool nor warm).

Fluid intakes, normalized to an hourly basis to accomodate differences in walk and rest durations, are consistent with the ratings of the two drinking systems. While the average water intake during the walk cycles for MDS (0.35 L/hr) was 46% greater than that for CS (0.24 L/hr), this difference was not statistically different (Table 3) due to interindividual variability (Appendix A). When individual fluid intakes for the rest periods were rank ordered (Appendix A), 8 of the 9 soldiers using the CS consumed more fluid during rest than all but 3 of the soldiers drinking with the MDS. Again, despite a 55% increment in fluid intake during the rest periods for CS (1.20 L/hr) relative to MDS (0.77 L/hr), statistical significance ($p<0.09$, Table 3) was precluded due to intersubject variability.

Soldiers using the MDS took an average of 3 drinks per walk, which was significantly more than during rest (Table 3), and significantly more than the CS group during both rest and walk periods.

Both CS and MDS groups exhibited a cyclic pattern of drinking with greater ($p<0.05$) fluid intake rates during the 10 min rests compared to the 50 min walks (Table 3). However, it is important to note that on a normalized basis, CS drank 5-fold and MDS drank 2.2-fold more water during the rest intervals.

Table 3. Comparison of Fluid Intake during Walk and Rest Periods

Variable	Current System (CS, n=9)	Mask Drinking System (MDS, n=9)
Intake during Walks (L/hr)	0.24 ± 0.20 ± 0.07 (0 - 0.59)	0.35 ± 0.25 ± 0.09 (0.09 - 0.95)
Intake during Rests (L/hr)	1.20 ± 0.53 ± 0.19# (0 - 1.92)	0.77 ± 0.68 ± 0.24# (0.13 - 2.39)
Number of Drinks taken per Walk+	0.6 ± 0.5 ± 0.2 (0 - 1.3)	3.0 ± 1.2 ± 0.5* (1.8 - 4.8)
Number of Drinks taken per Rest+	1.1 ± 0.2 ± 0.1 (0.8 - 1.5)	0.9 ± 0.3 ± 0.1# (0.5 - 1.2)

Values are Mean ± SD ± SE.
Values in parentheses represent the range.
\+ n=5 for Current System and n=7 for Mask Drinking System for number of drinks taken during walks and rest periods.
* Represents significant ($p<0.05$) difference between CS and MDS.
\# Represents statistical significance ($p<0.05$) between walk and rest values.

There were no statistical differences in total fluid intake (approximately 0.39 L/hr, Table 4) between groups, although the data indicated a trend toward higher total fluid consumption in the MDS group (Appendix B). Further, sweat rate (0.65 L/hr), body weight loss (0.24 kg/hr) and % rehydration (68%) were likewise not different (Table 4) between the CS and MDS groups.

Individual values for these variables are provided for the MDS and CS groups in Appendices C and D, respectively.

Table 4. Fluid Balance

Variable	Current System (CS, n=9)	Mask Drinking System (MDS, n=9)
Total Intake (L/hr)	0.36 ± 0.12 ± 0.04 (0.20 - 0.57)	0.42 ± 0.30 ± 0.11 (0.11 - 1.19)
Sweat Rate (Kg/hr)	0.63 ± 0.14 ± 0.05 (0.45 - 0.98)	0.67 ± 0.22 ± 0.08 (0.39 - 1.22)
Rehydration (%)[a]	67 ± 32 ± 11[b] (21 - 132)	68 ± 42 ± 15[c] (18 - 170)
Body weight loss (Kg/hr)[d]	0.22 ± 0.25 ± 0.09 (-0.19 - 0.78)	0.25 ± 0.25 ± 0.09 (-0.20 - 0.65)
Body weight loss (%/hr)[d]	0.32 ± 0.31 ± 0.11 (-0.23 - 0.89)	0.31 ± 0.29 ± 0.10 (-0.25 - 0.72)

Values are Mean ± SD ± SE.
Values within parentheses represent the minimum and maximum.
* Significant ($p<0.05$) difference between CS and MDS.
a % Rehydration = (total fluid intake/sweat loss) * 100.
b Subject who rehydrated 132% vomited after completing study.
c Subject who rehydrated 170% consumed four pieces of toast with margarine and jam, 284 grams orange juice and 340 grams instant breakfast in skim milk for breakfast. In addition, subject indicated that he maintained good hydration on evening prior to and on morning of study.
d Body weight loss is a positive number
Body weight gain is a negative number.

Performance measures were similar between groups. For example, there were no significant differences in exercise endurance between the two groups: CS = 232 ± 22 min, MDS = 225 ± 18 min. As anticipated, cumulative walk intervals elicited an increase ($p<0.05$) in the rating of perceived exertion with both systems. Quite surprisingly, soldiers using the MDS rated their final walk as "very hard" and slightly more difficult ($p<0.05$) than soldiers drinking with the CS who rated their final

walk as "hard". A statistically greater, but most likely not physiologically important, degree of tiredness was expressed by the MDS subjects (very tired) relative to the CS group (tired) following the final walk.

While no differences were observed in pre-exercise marksmanship performance between groups, a greater ($p<0.02$) vertical shot dispersion was observed post-exercise in the MDS group (Table 5). Shot groups were significantly more dispersed, both vertically and horizontally, post-exercise compared to pre-exercise irrespective of drinking system (Table 5).

Most of the subjects who terminated participation early reported symptoms of dehydration and hyperthermia (Appendix E). It is not surprising that no consistent pattern was noted for either drinking system since exercise times were similar. The most common complaints reported were, in descending frequency, headache, dizziness, cramps, nausea, and fatigue. All but one of the six soldiers completing the entire 300 min of walking complained of headache and fatigue. Responses to the Environmental Symptoms Questionnaire (ESQ, Table 6) indicated that symptoms of weariness, bodily aches, light-headedness, and thirst were also increased post-exercise with either drinking system. Relative to CS, soldiers using the MDS did not report an increased incidence in any of these symptoms except for an increased number of bodily aches ($p<0.01$) and light-headedness ($p<0.005$) (Table 6). The MDS did not impact on the subjective ratings of comfort or thermal sensation which were reported as "very uncomfortable" and "warm", respectively, by both groups.

Table 5. Marksmanship Performance

[a]Distance from Center of Mass of Target (mm)	
	CS
Pre-exercise	6.78 ± 2.04 ± 0.68
Post-exercise	7.29 ± 3.43 ± 1.14
	MDS
Pre-exercise	8.49 ± 4.41 ± 1.47
Post-exercise	9.47 ± 5.88 ± 1.96
[b]Shot Group Tightness by S.D. From Target Center of Mass (mm)	
	CS
Pre-exercise	2.40 ± 1.03 ± 0.34 [t]
Post-exercise	3.09 ± 1.36 ± 0.45
	MDS
Pre-exercise	3.23 ± 1.56 ± 0.52 [t]
Post-exercise	5.29 ± 4.24 ± 1.41
[c]Horizontal Shot Group Tightness (mm)	
	CS
Pre-exercise	6.01 ± 3.36 ± 1.12 [t]
Post-exercise	7.61 ± 2.42 ± 0.81
	MDS
Pre-exercise	8.84 ± 5.78 ± 1.93 [t]
Post-exercise	11.04 ± 7.04 ± 2.34
Vertical Shot Group Tightness (mm)	
	CS
Pre-exercise	5.77 ± 2.57 ± 0.86 [t]
Post-exercise	7.06 ± 2.52 ± 0.84
	MDS
Pre-exercise	7.13 ± 4.91 ± 1.64 [t*]
Post-exercise	11.86 ± 9.37 ± 3.12

a Distance is mean distance of all nine shots from the center of mass.

b Shot group tightness is calculated by taking the standard deviation of the distance from the center of mass.

c Horizontal shot group tightness represents a range, and is calculated by doubling the standard deviation of the X-coordinates. The same procedure is done for the Y-coordinates to get a measure of vertical shot group tightness.

t Statistically significant ($p<0.05$) between pre- to post-exercise.

* Statistically significant ($p<0.05$) between CS and MDS.

Table 6. Post-Exercise Environmental Symptoms Questionnaire

Complaint	Group	% of Responses Rated: none at all	slight	moderate	severe
Weariness	MDS	36	25	18	21
	CS	47	24	6	23
Headache	MDS	33	11	17	39
	CS	56	17	5	22
Heat	MDS	11	14	22	54
	CS	17	25	11	47
Bodily aches	MDS	35	22	18	25*
	CS	56	27	3	14
Light-headedness	MDS	24	47	4	25*
	CS	47	24	22	7
Thirst	MDS	38	29	18	15
	CS	62	20	9	9

Values indicate percentage of responses from all questions about the complaint for which group members rendered that numeric reply.
* Significant ($p<0.05$) difference between CS and MDS.

Increases in heart rate, rectal and skin temperatures and heat storage were effected within the first 50 min walk in both groups. Compared to MDS, significantly greater increases in rectal and skin temperatures (Table 7) were measured in the CS group, and consequently, significantly more heat was stored by soldiers in this group. Increases in heart rate (Table 7; approximately 70 bpm) which were similar for the two groups are quite marked for the average 4 1/2 work bouts completed.

Table 7. Heat Strain Indices

Variable	Current System (CS, n=9)	Mask Drinking System (MDS, n=9)
Heart Rate (bpm)		
Pre-exercise	88 ± 9 ± 3	94 ± 13 ± 5
Final walk	161 ± 15 ± 5 t	161 ± 16 ± 6 t
Δ HR	73 ± 16 ± 6	67 ± 19 ± 7
Rectal Temperature (°C)		
Pre-exercise	37.03 ± 0.24 ± 0.09	37.26 ± 0.34 ± 0.12
Final walk	38.82 ± 0.39 ± 0.14 t	38.53 ± 0.62 ± 0.22 t
Δ Tre	1.79 ± 0.38 ± 0.14	1.27 ± 0.42 ± 0.15 *
Skin Temperature (°C)		
Pre-exercise	34.23 ± 0.76 ± 0.27	34.55 ± 0.64 ± 0.23
Final Walk	36.70 ± 0.89 ± 0.31 t	36.46 ± 0.76 ± 0.27 t
Δ Tsk	2.47 ± 0.93 ± 0.33	1.91 ± 0.62 ± 0.22 *
Heat Storage (kcal/m²)		
Pre-Exercise	1224 ± 51 ± 18	1224 ± 78 ± 28
Final Walk	1294 ± 53 ± 19 t	1270 ± 84 ± 30 t
Δ HS	70 ± 11 ± 4	46 ± 15 ± 5

Values are Mean ± SD ± SE.
Δ = final walk - pre-exercise value.
Heat Storage (S) was calculated using the following formula [19]:
S = 0.84 * (BW)/(BSA) * Tbody
where: Body weight (BW) is in kg
Body surface area (BSA) = 0.00718 * Subject's height^0.725 * BW^0.425
Body temperature (Tbody) = (0.8 * Tre) + (0.2 * Tsk)
t Represents significance (p<0.05) between pre-exercise and final values.
* Represents significant (p<0.05) difference between CS and MDS.

DISCUSSION

In addition to the risk of contamination inherent in using the current through-mask drinking system, impermeable protective clothing and hooded mask increase the heat load and sweat rate [21]. Thus, in warm environments the inability of fluid consumption to compensate for excessive water losses through

sweating may constitute a sufficient level of hypohydration and hyperthermia to pose a potentially life-threatening risk to the soldier in MOPP IV configuration [21]. Therefore, a modified through-mask drinking system prototype was designed to facilitate drinking and, thereby, improve rehydration in soldiers working in MOPP IV configuration.

Responses to the drinking system questionnaires (Table 2) indicated that the MDS prototype was received more favorably than the CS during either work or rest. The MDS was rated as "neither easy nor hard" to use during both walk and rest periods. In contrast, ease of use, ease of connecting/disconnecting and ease of holding the canteen above head level for the CS were rated as "hard" during the walks and as "neither easy nor hard" during the rests. The CS group had to shoulder the rifle and decontaminate the mask and canteen connections prior to drinking; thus, it was not surprising that general use of the CS was rated more difficult than the MDS, particularly during the walks.

Because the water pumped from the canteen to mask with the MDS remains in the pumping bulb between drinks, it can warm to ambient temperature (32.6°C or 91°F). The first two mouthfuls of water originate from the handpump of the MDS and since warm water elicits reduced fluid intake [2,13,20], we anticipated that warm water in the pumping bulb may be a potential problem under desert conditions or during maneuvers in closed vehicles. However, under the conditions of the present study, the MDS prototype had no significant effect on the perceptions of either the taste (rated neither like nor dislike) or the temperature (rated

neither cool nor warm) or the total quantity of fluids consumed. Fluid intake rate (Table 4) was not compromised in soldiers using the MDS (0.42 L/hr) compared to the CS (0.36 L/hr).

One of the theoretical advantages of the MDS is that during periods of high stress and/or work, a soldier may replace fluid losses easily and without interruption due to the single-handed operation. The MDS prototype, which was evaluated as a potentially safer and more convenient system than the CS, did not compromise fluid intake under the present experimental conditions. In fact, although not statistically significant, the 46% greater fluid intake during walk periods in MDS compared to the CS group supports our previous observation [21] that significantly more fluid was consumed by soldiers using another MDS prototype.

In addition, soldiers using the MDS took, on average, 3 drinks per 50 min walk compared to 1 drink taken by the CS group (Table 3). This is important because Kenney [14] reported that small frequent sips of water are instrumental in preventing hypohydration and its attendant hyperthermia, particularly when working in hot, humid environments. Likewise, consumption of large volumes of water with each drink may exceed the gastric emptying capacity of about 290 ml/15 min [5] and produce gastric upset. For example, one soldier using the CS continually consumed between 1/2 to 2 quarts of water with each drink during the walks, rehydrated to 132%, gained 1.1 kg in body weight, and had lower than average increases in heart rate, rectal temperature and heat storage. However, he displayed symptoms of

dizziness and nausea, and ultimately vomited shortly after completing the 6 hr trial. In contrast, one soldier of the MDS group, drank frequently and in smaller volumes, rehydrated to 170%, completed the 6 hr trial, displayed heat strain indices well below the average group values, and did not become ill.

The elevated intake during exercise, increased frequency of drinking and greater ease of use when drinking with the MDS are important observations when considering fluid requirements during active training/operations wherein periods of inactivity are usually limited, and indicate that a MDS prototype warrants further development.

In a contaminated environmenc a second potential benefit of the MDS prototype is the one-time connection between the mask drinking tube and canteen. This eliminates the requirement to decontaminate all connections with each drink, and thereby reduces the risk of accidental contamination associated with drinking with the CS. Failure to decontaminate mask and canteen connections prior to drinking was noted in 2 soldiers using the CS. Surprisingly, these 2 failures occurred early in the trial (Rests #1 and #3) suggesting memory lapses which were not associated with hypohydration, fatigue or hyperthermia.

Because the environmental conditions, work intensity and clothing ensembles were identical for both groups, the significantly higher rectal temperature and greater heat storage in CS were not expected. It is possible that increased heat production in the CS group may be due to the additional work required for decontamination and the multiple steps required for

drinking. Further, increased metabolic activity due to the frustration and anxiety associated with drinking with the CS may have contributed to the greater thermal stress in this group.

Post-exercise, test subjects reported an increased number of complaints related to dehydration and hyperthermia irrespective of the drinking system used (ESQ, Table 6). The three most common complaints resulting in early withdrawal from the study were headache, dizziness and cramps, with no consistent pattern noted for either drinking system (Table 6, Appendix E). These symptoms are noteworthy since only 33% (6/18) of the subjects in the current study completed all six 50 min work bouts. These data are consistent with those of our previous study [21].

Because drinking with the MDS had no adverse effect on fluid intake or rehydration, it was not surprising that only minor effects of drinking system on performance measures were observed. Both the CS and MDS groups completed an average of only 228 min out of a possible 300 min. While this represented 76% of the potential exercise tolerance time, Avellini [3] has also observed reductions as high as 49% in tolerance time under mild climatic conditions when impermeable protective gear was worn. The only significant difference in marksmanship performance between the two groups was the greater vertical shot group dispersion in seen post-exercise for MDS compared to CS. This difference is most likely due to the greater tiredness and symptoms (ESQ, bodily aches, lightheadedness) expressed by the MDS group.

We have concluded that not only did the MDS prototype not compromise total fluid intake or exercise endurance during the

experimental trial, but several observations indicate the advantages of this modified through-mask drinking system prototype. For example, during the walks, a trend toward higher fluid consumption was observed in the MDS group relative to the CS, clearly advantageous if tactical scenarios prevent adequate rest intervals. Further, ratings on the ease of use and reduced requirements for canteen/coupling decontamination indicate both subjective and objective rationale for further evaluation of the MDS.

Summary Table of Differences

Relative to the current system, the advantages and disadvantages of using the modified mask drinking system (MDS) are shown.

Measurement	Advantage using MDS	Disadvantage using MDS
Heat storage	+	
Skin temperature	+	
Rectal temperature	+	
Ease of use while walking	+	
Ease of use while at rest	+	
Decontamination failures	+	
Number of drinks per walk	+	
Fluid intake during work	●	
Rating of perceived exertion		+
ESQ : light-headedness		+
bodily aches		+
Fatigue/tiredness		+
Weaponeer firing errors		+
Fluid intake during rest		●
Total fluid intake	0	0
Percent rehydration	0	0
Sweat rate	0	0
Body weight loss	0	0
Number of drinks per rest	0	0
Exercise time	0	0
Heart rate	0	0

+ Indicates advantage or disadvantage.
● Indicates trend.
0 Indicates no difference between current system and MDS.

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Appendix A. Rank Order of Fluid Intake during Work and Rest Periods.

Order	Group	Intake during Work (L/hr)	
1	MDS	0.95	
2	CS	0.59	
3	CS	0.54	
4	MDS	0.45	
	MDS	0.45	
5	MDS	0.36	
6	CS	0.29	
7	CS	0.26	
8	MDS	0.25	median MDS
9	CS	0.24	median CS
10	MDS	0.22	
11	MDS	0.19	
12	MDS	0.14	
13	CS	0.10	
14	MDS	0.09	
15	CS	0.05	
16	CS	0.04	
17	CS	0.00	

Order	Group	Intake during Rest (L/hr)	
1	MDS	2.39	
2	CS	1.19	
3	CS	1.77	
4	CS	1.41	
5	CS	1.30	
6	CS	1.26	median CS
7	MDS	1.22	
8	CS	1.21	
9	MDS	1.14	
10	CS	1.11	
11	CS	0.81	
12	MDS	0.77	
13	MDS	0.41	median MDS
14	MDS	0.34	
15	MDS	0.33	
16	MDS	0.20	
17	MDS	0.13	
18	CS	0.00	

Appendix B. Rank order of total fluid intake rates

Order	Group	Total Fluid Intake (L/hr)	
1	MDS	1.19	
2	CS	0.77	
3	MDS	0.57	
4	CS	0.51	
5	CS	0.44	
	MDS	0.44	
6	CS	0.42	
7	MDS	0.39	
8	CS	0.38	median CS
9	MDS	0.35	median MDS
10	CS	0.30	
11	MDS	0.26	
12	MDS	0.25	
	CS	0.25	
13	CS	0.21	
14	CS	0.20	
15	MDS	0.18	
16	MDS	0.10	

Appendix C. Individual values for various physiological parameters.

Subjects using the MDS

Subject		Exercise Time (min)	Tre (°C)	Tsk (°C)	Heart Rate (bpm)	Fluid Intake (L/hr)	Heat Storage (kcal/m²)	RPE
1	initial		37.78	35.55	100		1329	11
	final	150	39.39	37.45	186	0.57	1387	15
2	initial		37.24	34.20	99		1187	11
	final	300	38.29	35.08	123	1.19	1220	12
3	initial		36.70	34.50	69		1227	11
	final	212	37.75	36.19	158	0.18	1265	17
4	initial		36.74	34.47	77		1123	13
	final	235	37.97	35.95	161	0.26	1165	19
5	initial		37.46	34.44	107		1170	11
	final	300	39.40	37.34	161	0.44	1233	18
6	initial		37.51	33.71	101		1285	13
	final	200	37.99	36.12	159	0.39	1311	19
7	initial		37.05	35.68	108		1103	9
	final	150	37.99	37.42	170	0.25	1137	17
8	initial		37.51	33.81	99		1284	11
	final	254	39.02	36.56	165	0.35	1352	17
9	initial		37.33	34.59	87		1309	11
	final	223	38.94	36.03	164	0.11	1364	17

Tre = Rectal Temperature
Tsk = Skin Temperature
RPE = Rating of Perceived Exertion

Appendix D. Individual values for various physiological parameters.

Subjects using the CS

Subject		Exercise Time (min)	Tre (°C)	Tsk (°C)	Heart Rate (bpm)	Fluid Intake (L/hr)	Heat Storage (kcal/m^2)	RPE
1	initial		36.99	35.04	87		1194	11
	final	198	39.50	37.84	156	0.51	1278	15
2	initial		37.34	34.21	97		1272	11
	final	175	39.10	37.05	174	0.38	1346	13
3	initial		36.91	35.42	80		1161	9
	final	300	38.61	35.95	138	0.22	1213	13
4	initial		37.00	32.69	89		1218	11
	final	200	38.08	35.50	138	0.42	1271	15
5	initial		36.96	33.84	101		1228	11
	final	300	38.57	36.48	160	0.77	1289	14
6	initial		36.90	34.33	83		1133	13
	final	300	39.10	37.93	164	0.30	1209	19
7	initial		36.89	34.59	83		1261	11
	final	300	38.78	35.79	159	0.44	1340	12
8	initial		37.57	34.38	100		1294	11
	final	171	39.09	37.66	176	0.25	1360	15
9	initial		36.73	33.59	73		1260	10
	final	144	38.61	36.11	182	0.20	1339	15

Tre = Rectal temperature
Tsk = Skin temperature
RPE = Rating of Perceived Exertion

Appendix E. Reasons for Terminating Participation

Order	System	Exercise Time (min)	Reason for Termination
1	CS	144	HR $\geq$ 180 bpm
2	MDS	150	Trouble breathing
	MDS	150	headache, HR $\geq$ 188 bpm
3	CS	171	Stomach cramps, dizzy, HR $\geq$ 176 bpm
4	CS	175	HR $\geq$ 182 bpm
5	CS	198	Fatigue, lead feet, Tre $\geq$39.5°C
6	CS	200	Blisters on feet, headache, dizzy, leg aches
	MDS	200	Backache, headache
7	MDS	212	Nausea, dizzy
8	MDS	223	Leg cramps, dizzy
9	MDS	235	Headache, leg cramps, legs itch (reaction to charcoal), flatulence
10	MDS	254	Leg cramps
11	CS	300	COMPLETED TEST but had headache, nausea, vomited
	CS	300	COMPLETED TEST but had headache, hunger
	CS	300	COMPLETED TEST but had headache
	CS	300	COMPLETED TEST but had fatigue, hunger
	MDS	300	COMPLETED TEST but had headache
	MDS	300	COMPLETED TEST but had headache, fatigue

CS Current system.
MDS Mask drinking system.

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